SMITHSONIAN INSTITUTION

ASTROPHYSICAL OBSERVATORY

OPTICAL SATELLITE-TRACKING PROGRAM

Carried out under Grant Number NsG 87

from the

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Semiannual Progress Report No. 15

July 1 through December 31, 1966

Project Director: Fred L. Whipple

CAMBRIDGE, MASSACHUSETTS, 02138

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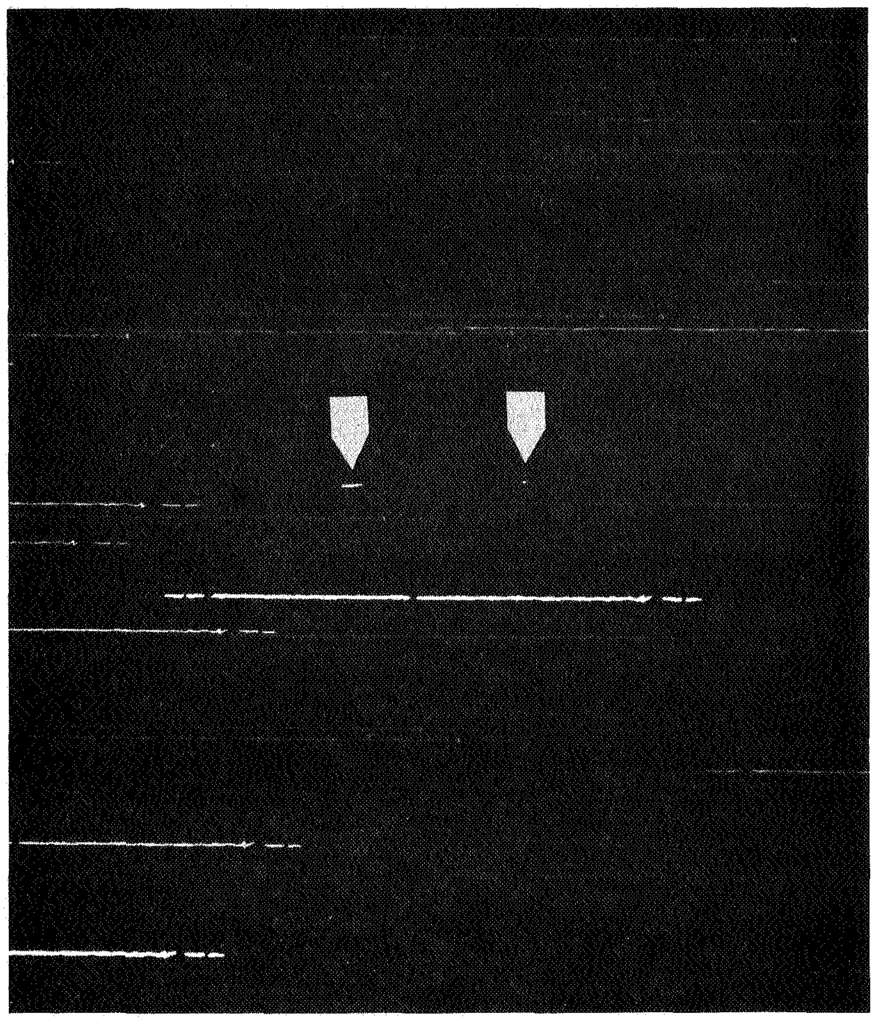

Photograph of 1966 31A and 1966 31C

This photograph of 1966 31A (OAO) and 1966 **31C** was taken at the Smithsonian astrophysical observing station at Organ **Pass,** New Mexico, on April 10, 1966, at $03^h52^m50.190^s$ UT. Object 31A is the white streak that is about 1/8 of an inch long and that is located in the center of the photograph. Object 31C is the faint dot ahead of 31A by approximately 21 arcmin.

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HIGHLIGHTS

An examination has begun of the geophysical investigations that will be possible with improved tracking accuracy, and a Summer Seminar was held to consider these geodetic possibilities.

Observatory efforts have resulted in significantly improving international cooperation in geodesy.

A theoretical model of diurnal variations in the upper atmosphere is being developed.

The possibility of winds in the upper atmosphere is being investigated.

Several studies are under way to define planetary perturbations.

Relativistic effects that might be observable in the motions of artificial satellites are being studied.

The number of simultaneous observations has increased 60% since April 1966.

During the period of this report, the Baker-Nunn camera network made 33,443 observations from 68, 366 predictions. Moonwatch teams reported 8905 observations, an all-time record.

The Observatory has established the Smithsonian Computer Center and leased a CDC 6400. All computer programs are being rewritten for that equipment.

More than 15,500 precise reductions of Baker-Nunn films were completed during this period.

On June 24, the Baker-Nunn camera station in South Africa photographed the inflation of PAGEOS-A and the apogee burn of the Agena-D.

The Baker-Nunn camera and associated equipment in Iran were moved to Ethiopa; those in Curaqao, to Brazil; and those in Villa Dolores, Argentina, to Comodoro Rivadavia in the same country.

K-50 cameras were installed at the vacated Baker-Nunn camera sites in Iran and Curaqao, and a third K-50 became fully operational in Greece.

Laser range measurements in large numbers have been obtained at the New Mexico station.

DATA ACQUISTION

SATELLITE-TRACKING AND DATA-ACQUISITION DEPARTMENT

Normal Operations

The department continued normal operations by tracking satellites as assigned by the National Aeronautics and Space Administration and as needed to meet the requirements of the Observatory research program.

Operational statistics. Tables 1 and 2 provide statistics on operational results for the second half of 1966 compared to the second half of 1965, and successful observations from individual observing stations.

Launch support. We provided launch backup for the early orbital determinations of PAGEOS, Nimbus C, Gemini 10, Agena 10, EGRS 7, ERS 15, Gemini 11, Agena 11, TOS A, EGRS 8, OV 4, Gemini 12, ATS B, and BIOS A, and expected support for Lambda before the end of December. The Agena 8 was tracked from time of launch to the Gemini-10 mission in July.

The Saturn Apollo 202 was photographed by the Baker-Nunn camera in South Africa 40 minutes after launch, at an altitude of 700 miles.

The separation of the Lunar Orbiter spacecraft was photographed by the Baker-Nunn camera in Australia on August 10.

Simultaneous observations. We continued the cooperative program to photograph satellites with the Air Force Baker-Nunn stations at Cold Lake, Canada, Edwards AFB, California, Oslo, Norway, and Johnston Island.

The astrophysical observing stations in Spain and Athens participated in a simultaneous observation program of the Echo satellites with cameras of the Western European Subcommission of the International Commission for Artificial Satellites.

The Baker-Nunn cameras in Ethiopia and South Africa photographed PAGEOS simultaneously with NASA Mots cameras in Africa.

The Baker-Nunn cameras in New Mexico, Japan, India, Spain, Curaçao, Florida, Ethiopia, Hawaii, and the K-50 station in Iran photographed PAGEOS simultaneously with cameras of the U. S. Coast and Geodetic Survey.

Presentations. On October 11, at the Goddard Space Flight Center, STADAD operations staff presented to officials of NASA's GSP'C, Langley Research Center, the Lewis Research Center, the photographs taken of the inflation of the PAGEOS satellite and the Agena-booster burn (see Figure 1).

TABLE 1

COMPARISON OF OPERATIONAL RESULTS

July-December 1965, 1966

Month	Number of Predictions 1965	1966
July	9,910	12, 280
August	10,541	11,412
September	11,075	11,137
October	12,318	11,165
November	12,818	10,952
December	11,626	11,420
Total:	68,288	68,366

Increase in number of predictions 0. 11%

Month	Number of Successful Observations 1965	1966
July	4, 956	5,960
August	5,424	5,672
September	5,528	5,685
October	6, 531	5,555
November	5,191	5, 206*
December	5,161	5, 365*
Total:	32,795	33,443

Increase in number of observations 0. 2%

*Including estimates for Japan, India, and Brazil for December.

TABLE 2

SUCCESSFUL OBSERVATIONS BY INDIVIDUAL TRACKING STATIONS

July-December 1965, 1966

Station	1965	1966	
	Number of Successful Observations		
New Mexico (SC-1)	3,077	3,357	
South Africa (SC-2)	3,436	3,584	
Spain (SC-4)	2,076	4,015	
Japan (SC-5)	951	1,100*	
India (SC-6)	2, 235	2, 435*	
Peru (SC-7)	2,851	2,652	
Iran (SC-8)	3,726	315	(closed July 15)
Curaqao (SC-9)	2,841	235	(moved July 28)
Florida (SC-10)	1,970	2,793	
Villa Dolores, Argentina (SC-11)	3,480	2, 029	(closed Oct. 28)
Hawaii (SC-12)	2,823	3, 263	
Australia (SC-23)	3, 329	4,039	
Ethiopia (SC-28)		2, 360	(from Aug. 15)
Brazil (SC-29)		777*	(from Sept. 27)
Comodoro Rivadavia, Argentina (SC-31)		489	(from Nov. 14)
Total	32,795	33,443	

*Including estimates for Japan, India, and Brazil for December.

In response to a special request, photographs were taken of Nimbus C by the network, and a presentation of them was given at GSFC by the operations staff. Project officials were interested in the specialized tracking of the Nimbus C to confirm spacecraft stabilization.

Baker-Nunn Station Moves

Three new Baker-Nunn stations became operational in the second half of 1966.

On July 22, the Baker-Nunn camera and equipment were moved from Shiraz, Iran, to Addis Ababa, Ethiopia. The Ethiopian station was operational August 15, 1966. On July 28, the Baker-Nunn camera and equipment were moved from their former site in Curaçao, Netherlands Antilles, to the new site in Natal, Brazil. The Brazil station was operational September 27. On November 1, the camera from Villa Dolores, Argentina, was moved south to the new Argentina site at Comodoro Rivadavia and was operational November 14, 1966. Bob Citron, Frank Budreski, and Bob Bennett, managers of the Ethiopia, Brazil, and Argentina stations, respectively, did much of the ground work of setting up the stations.

SAO K-50 stations. An SAO K-50 camera was installed in Shiraz, Iran, at the former Baker-Nunn location. The camera became operational September 10 and has been photographing the Echo satellites, PAGEOS, and GEOS simultaneously with the Baker-Nunn stations in Ethiopia, Spain, India, and South Africa, and the SAO K-50 camera at Athens, Greece.

A second SAO K-50 camera was moved to Curaqao on the Baker-Nunn site, and was operational October 12. It has been photographing the bright satellites simultaneously with the Baker-Nunn cameras in Florida, New Mexico, Peru, and Brazil.

The first SAO K-50 field station, operated jointly by SAO and the National Technical University, was set up in Athens, Greece, in April. The newly designed chopping shutter for the camera was sent to the Athens station in August; with its installation the camera became fully operational in the stationary mode. Development of the tracking mode of the camera will continue there.

Engineering Support

Station and camera maintenance. The Baker-Nunn station moves to Ethiopia, Brazil, and Comodoro Rivadavia were assisted by STADAD engineers, who supervised camera dismantling, setup, and optical adjustment in the latter two sites.

During the station move the mirror for the Ethiopia camera was cleaned and returned to the station to meet the planned operational date.

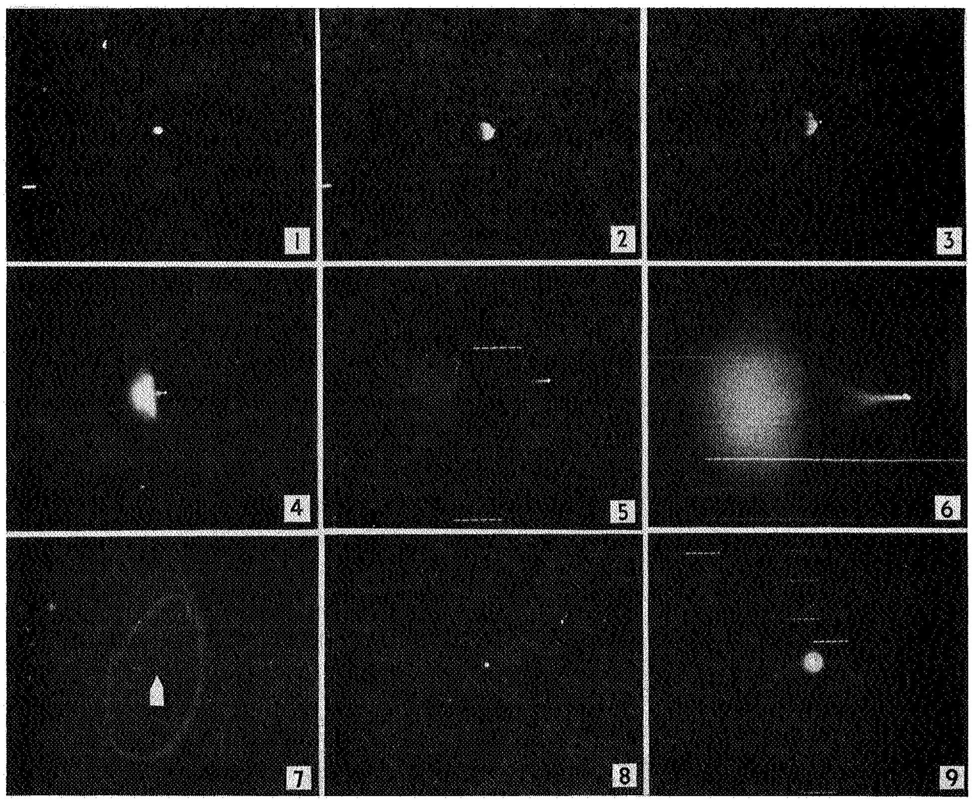

Figure 1. Baker-Nunn film enlargements showing various Agena burns and PAGEOS-A inflation.

	Time
Photograph #1	$01^{h}\ 24^{min}\ 37^{sec}$
Beginning of First Burn	
Photograph #2	$01^{h}\ 24^{min}\ 39^{sec}$
First Burn and First Cloud forming (4 × 4 miles)	
Photograph #3	$01^{h}\ 24^{min}\ 41^{sec}$
First Burn ceased	
Photograph #4	$01^{h}\ 24^{min}\ 59^{sec}$
Outer Faint Semicircular Cloud formed by the Second Burn. New dense central cloud being formed by the Third Burn.	
Photograph #5	$01^{h}\ 25^{min}\ 51^{sec}$
Fourth Burn starting	
Photograph #6	$01^{h}\ 26^{min}\ 14^{sec}$
8.8-second time exposure showing clouds 2 and 3 expanded to 60 X 120 miles, and the continuing Fourth Burn.	
Photograph #7	$01^{h}\ 27^{min}\ 45^{sec}$
The very faint dot is the spacecraft prior to balloon inflation.	
Photograph #8	$01^{h}\ 27^{min}\ 55^{sec}$
The balloon has partially inflated.	
Photograph #9	$01^{h}\ 36^{min}\ 40^{sec}$
The balloon has completely inflated.	

A spare corrector cell was refurbished at Perkin-Elmer and fitted with a protective window. To meet the adverse environment in Comodoro Rivadavia, this assembly was sent there in time for station operation.

A total of seven corrector-cell protective windows have been completed by Perkin-Elmer Corporation; six of them have been placed in storage. Two more remain to be fabricated.

A partial field cleaning test was performed on the front surface of the Spain corrector cell to determine the advisability of a thorough field cleaning. Results indicated that field cleaning would not be adequate.

Precision-timing system. During this reporting period, EECo precision-time standards were installed on cameras in Australia, India, and Japan. Dual-channel EECo standards, for increased reliability through redundancy, were installed in the former two. All Baker-Nunn stations now employ the highly accurate ECCo system.

With the installation of a rubidium laboratory frequency standard and appropriate VLF radio receivers, the Headquarters Monitor Station has reached full capability to monitor very low frequency radio transmissions.

Personnel made three trips to several stations. Using a portable crystal clock, they set each ECCo clock and correlated its time with local time standards. Each trip also included EECo instruction and system maintenance work. The first trip was arranged to assist the clock installation in the Ethiopia station and to check the performance of the newly installed time standards in the Greece, India, and Australia stations. A time comparison was also made at the Observatoire Cantonale in Neuchatel.

The time setting in Spain included a comparison with time services WWV (Washington), GBS (Rugby, England), and that of the Spanish Naval Observatory. Japan and Ethiopia were visited on the third trip to assist station time-keeping and improve timekeeping ties with the other stations in the Baker-Nunn system.

Vehicles. A second new Chevrolet carryall has been shipped to the Brazilian station.

A Land Rover originally scheduled for Iran has been redirected to Peru to replace a vehicle there.

A new Ford F-100 truck has been ordered for the India station.

Geodetic Camera Development

Design solutions for several problems observed during the field operation of the SAO K-50 cameras have been found. Current problems center on shutter and chopper performance. Field calibration to resolve uncertainties in the operation of these components is in progress.

Laser Activities

Laser range measurements of high resolution have been acquired in large numbers on a continuing basis at the New Mexico astrophysical observing station. Table 3 shows the number of precise range measurements made per month on the three retroreflector-equipped satellites.

In August, several improvements on the present ranging equipment were effected, with improved operation as a result. These modifications permitted us to gain more information about the performance characteristics of the current laser system in relation to such factors as the velocity aberration effect, electrical interference of the laser on the photoreceiver, and equipment circuitry delays.

A proposal was sent in July to NASA Office of Advanced Research and Technology (OART), requesting funding for acquisition and testing of a prototype laser system. In addition, specifications for a static pointing mount and telescope photoreceiver were sent to vendors for quotations. Proposals from vendors for these two components as well as for the laser transmitter (RFP issued earlier) were evaluated, and suppliers were selected.

Special Observations

During the reporting period four comets were photographed for position determinations. Comet Barbon and Comet Kilston were photographed during late August through November. Comet Rudnicki was observed from late November through December. Comet Ikeya-Everhart was kept under surveillance from September *to* early November.

During July, the astrophysical observing stations in South Africa, Spain, Iran, Peru, and Argentina photographed flare star V 1216 Sgr and variable V Sge in conjunction with the radio telescope at Jodrell Bank, England. In October, photography of flare star UV Ceti was carried out in conjunction with the Jodrell Bank radio telescope by the stations in Ethiopia, South Africa, Spain, Brazil, Villa Dolores in Argentina, and Peru. UV Ceti was also photographed in October by the observing station in Australia in conjunction with the radio telescope of the CSIRO.

Moonwatch

The number of Moonwatch teams with registered observing sites has now risen to 121, distributed in 22 countries. There are 25 additional reentry observers.

In the second half of 1966, 8905 observations were reported, making the total for the year 14,928. This is an all-time record.

Many more observations are now being contributed to the Low-Perigee Program. It is particularly gratifying to be able to report increased interest in the Program in the Southern Hemisphere. This has permitted more accurate orbit elements to be computed for the satellites concerned.

TABLE 3

LASER RANGE MEASUREMENTS (1.5-m RESOLUTION)

July to December 1966

Month	BE-C	BE-B	GEOS A
July	15	114	71
August	1	4	64
September	2	65	37
October	14	49	23
November	--	23	77
December		(incomplete)	
Total	32	255	272
Total laser measurements			559

Predictions for 49 satellite decays have been sent to teams possibly having visibility. Two confirmed sightings were reported.

The air pilot patrol organized by Denver Moonwatch continues in operation. Fifty-five airlines representing 28 different countries and involving 28,235 flight personnel are involved. Together, they "look along" 1,737,038 unduplicated-route miles of airway.

The first of the new telescope mounts have been sent out: They are expected to be in use in 2 or 3 months' time.

In July, August, and September 1966, the Chief of the Moonwatch Division made a round-the-world trip in the course of which he visited 20 Moonwatch teams in Europe, South Africa, Australia, and New Zealand. Arrangements were made by which the southern teams can now receive predictions more promptly than was previously possible.

COMMUNICATIONS

Communications are now being handled effectively between the new Baker-Nunn sites in Ethiopia, Brazil, and southern Argentina. Special attention in the establishment of more efficient communications also has been given the K-50 geodetic camera sites in Greece, Iran, and Curaçao.

Message traffic to the stations in Ethiopia and Greece is handled over the military network of the Defense Communications System (DCS) and tie-lines from the embassies in Addis Ababa and Athens, respectively. Each station has the capability of an alternate means of communications, since they have access to International Telex facilities. The Iran station is served by both the DCS network and commercial cables. Utilizing the DCS facilities for some of our traffic has resulted in substantial savings.

The Baker-Nunn camera station in Brazil is now served via commercial cables. We hope to establish radio-teletype communications with the NASA network in the next fiscal year. A direct line has been installed between RIO-RECIFE-NATAL and the Brazilian Air Force Rocket Base on which the station is located.

Communications are quite reliable between the SAO station in Comodoro Rivadavia and the NASA station in Santiago, Chile, via radio-teletype facilities. The NASCOM communications network is utilized between SAO and Santiago on reliable circuits established several years ago.

A new 100-wpm teletype circuit was installed between the Communication Center and SAO's new building in Brighton, Massachusetts.

During the recent eclipse of the sun, the Communications Department coordinated efforts with several observing teams in and around Arequipa, Peru, for the purpose of observing and recording data. SAO Communications also served as the central point for handling traffic on the eclipse for the SAC Peak and Kitt Peak Observatories as well as processing traffic to and from the Air Force Cambridge Research Laboratories at Hanscom Field in Bedford, Massachusetts.

DATA PROCESSING

DATA DIVISION

Progress

Operational satellite tracking. The Data Division supplied tracking predictions to the Baker-Nunn, Moonwatch, and laser stations. A more refined laser prediction program is being put into production. We sent predictions to the modified K-50 geodetic cameras at Shiraz, Iran, Curaqao, Netherlands Antilles, and Athens, Greece, which produced observations of the GEOS-A flashing-light satellite. In addition, they received simultaneous predictions on Echo 1, Echo 2, and PAGEOS.

As of mid-December, 278 predictions had been sent to the Baker-Nunn stations on 16 NASA launches, and the cameras had made 59 observations. At the request of NASA, the Observatory's scientists, and others, a total of 54 satellites were tracked by the Baker-Nunn cameras during the second half of 1966. Orbital elements, field-reduced and photoreduced observations, predictions, long-range forecasts, and auxiliary data on the satellites being tracked by the Observatory were provided the following agencies: Tokyo Astronomical Observatory, University of California, U. S. Coast and Geodetic Survey, the Department of Defense, Langley Research Center, Bell Telephone Laboratories, Marshall Space Flight Center, Air Force Cambridge Research Laboratories, University of London, Raytheon Corporation, and GIMRADA.

Under a cooperative observing program with NORAD, the Observatory was asked to provide tracking support on eight different objects for varying periods of time over the past 6 months. The Observatory in turn asked the Air Force Baker-Nunn cameras to provide simultaneous observations on as many as five satellites in 1 month, in support of our geometrical and dynamical geodesy program.

The cooperative observing program with the Royal Radar Establishment at Malvern, England, continued; simultaneous observations were obtained between Malvern and several SAO Baker-Nunn sites.

A cooperative observing program with a European network of 17 stations and the SAO sites at San Fernando, Spain, and Athens, Greece, has been established using the Echo 1 and Echo 2 balloon satellites. Twenty-five successful simultaneous observations had been made by October 30, 1966.

The SAO Standard Earth coordinates have been adopted for the Baker-Nunn camera sites.

The Observatory has participated and will continue to participate extensively in the National Geodetic Satellite Program and will continue to predict on the PAGEOS-A balloon.

Star Catalog tape sales. Twelve copies of the Star Catalog on magnetic tapes were sold, bringing total sales to 49 (at $50.00 per sale = $2450): 4 were sold in 1963; 11 in 1964; 12 in 1965; total of 22 in 1966. Customer correspondence has been relatively heavy.

Printed catalog. Since publication of the SAO Star Catalog in book form in March 1966, all orders placed through SAO have been referred to the Government Printing Office. A few additional complimentary copies have been distributed. The total SAO-SI reserve still numbers about 100 copies.

Other. A cross reference to the largest and most useful identification catalogs of stars, the BD, CD, and CPD, has been started; it is being done as a fill-in job by the keypunchers and will take about a year to complete. Its value to the astronomical community will be considerable.

Reprogramming of the several most important Star Catalog programs has been started for the CDC 6400.

A program to discover errors on the Star Catalog tapes by comparison with reductions done in the Photoreduction Division has been written and used sporadically, but so far no stars have been found to be in error.

The plotting and inking of the 608 star charts were completed in September, and the charts are now at the U. S. Coast and Geodetic Survey undergoing reduction to the two appropriate scales, preparation of the full chart reseau, labeling, and preparation of interpolating scales for both magnitudes and coordinates. At present, nearly all processes are complete for one-half the charts. Full reproduction in quantity will proceed early next year.

PREDAT, the Precision Control Section of the Data Division, has been established, and is expected to issue periodic bulletins on items of importance to precise reductions. PREDAT bulletins will have extensive distribution, both within and without SAO.

GPI and solar-flux data are distributed to interested parties monthly, and timing and polar motion data on request.

Among several new projects, the regular and systematic collection of data pertinent and necessary to accurate position and time reduction has been initiated. Included are measures of the motion of the pole (from both the IPMS and the BIH); A1 vs UT; WWV vs A1 (from several time services); current data on solar flares and magnetic storms; and relative sunspot numbers.

Conferences

Representatives of the Data Division attended a meeting on the "Construction and Use of Star Catalogs" sponsored by NSF and organized by the Naval Observatory, and presented a paper on SAO experience. The Astronomical Journal will publish the paper as part of the proceedings of the meeting.

PHOTOREDUCTION DIVISION

Progress

Photoreduction purchased a new solid-state digitizing system to replace the least reliable of our five original digitizing systems.

The permanent film-storage facility was moved to larger, less expensive quarters that should satisfy storage needs through 1970.

More than 15,500 precise reductions of Baker-Nunn satellite observations were completed during this period. The Division's cumulative output now exceeds 175,000 reductions.

The new combination preparation-and-reduction program was Completed. It is now being modified for use on the CDC 6400 system and should be operational in January 1967.

Work was begun on a general-purpose plate-reduction program that will allow the reduction of a variety of photographic plates on a routine basis. We expect that it will be operational in February 1967.

The assignment of a permanent liaison officer between Photoreduction Division and STADAD has resulted in improved communications between the two groups.

The digitization of the microdensitometer has been postponed until June 1567, owing to manufacturer's delays.

A "Project Concept" was initiated, and "Leaders" were assigned responsibility for several projects now in progress. They are authorized to deal directly with functional group supervisors to schedule the manpower and equipment necessary for their projects.

COMPUTATIONS

A CDC 6400 computer has been installed at 185 Alewife Brook Parkway and is operating satisfactorily.

Work is progressing on a remote-control console for 60 Garden Street that will provide direct access to the CDC 6400.

Programs

SCROGE (The Baker-Nunn Prediction Program). A FORTRAN version of SCROGE has been developed for the CDC 6400.

Simultaneous SCROGE. This program is constantly being modified and improved.

Standard Earth. The relevant programs have been improved and converted for CDC 6400 usage. Production runs should being shortly.

Tesseral harmonics. The tesseral harmonics program is now running on the CDC 6400.

DOI (The Differential Orbit Improvement Propram). A CDC 6400 version of DOI is now available for production runs. Work continues toward obtaining a new scientific DOI that will incorporate doppler data.

Laser Prediction Program (AIMLASR). We are developing a high-precision satellite-prediction program for the laser tracking project. It has been enlarged to include convenience options for input, extra computations involving the earth's shadow cone, and an expanded output. Instead of a single prediction, a sequence of predicted positions can now be printed for one pass of a satellite.

Conversion efforts. The Preparation Program, the Reduction Program, and Ephemerides 0, 2, 4, 6, and 7 are in the final stages of CDC 6400 conversion.

Computer Operations

Progress. With the installation of the CDC 6400, the Smithsonian Computer Center was established. The Center will be a self-supporting unit with all users paying their proportional share.

During the past 6 months, the Computer Operations Division underwent some far-reaching changes. Rental of the CDC 3200 medium-scale computer was discontinued in September, after which the size of the computer room was expanded and additional air-conditioning and electrical capacity were installed.

In October a large-scale CDC 6400 computer was installed. This marks the first time in almost 5 years that SAO has had an in-house computer capable of handling all current programs.

Turn-around time for debugging programs and running production jobs has been reduced significantly.

Equipment Studies

Automatic film reader. Studies continue on the use of a computer-driven film reader for photoreductions.

DATA UTILIZATION

RESEARCH AND ANALYSIS

Dynamical and Geometrical Geodesy and Geopotential Investigations

Mr. E. M. Gaposchkin completed documentation of the SAO Standard Earth involving a detailed description of the Differential Orbit Improvement program as used in the analysis of the Standard Earth. Additional data, including GEOS, became available in the last year; they were used to improve or determine some of the high-order tesseral harmonics.

The new computer has necessitated rewriting all the research programs. Under Mr. Gaposchkin's direction, the program to compute tesseral harmonics and station coordinates using optical observations was completed to the point of the previous program. The reprogramming opportunity is being used to reformulate the theoretical foundation of the programs. This is necessary owing to the increased accuracy and greater variety of the data now available. We plan that all theoretical developments will be accurate to 1/2 m. Programs are being developed to evaluate, in addition to the existing perturbations, the short-period perturbations due to atmospheric drag, the long-period atmospheric drag, and radiation-pressure perturbations.

We are currently using the range data from the SAO laser. We are also developing the capability to use the NASA range and range-rate data and the APL doppler data. As part of this process we have begun a study to improve the locations of the NASA range and range-rate sites. This should allow us to provide particular NASA investigators with the most accurate ephemeris available.

Mr. L. Solomon has commenced a study of the GSFC range and range-rate tracking system, to lead to the use of its data with the SAO data in orbit computation and in the various geodetic programs. The study will cover conversion of the data to SAO formats, analysis of sources of error, and computation of new station coordinates from satellite observations.

Mr. Gaposchkin has begun to examine the geophysics that the present satellite results and the future improved accuracy will lead to. In particular, his effort includes a survey of the current state of knowledge of the motion of the pole, the earth's wobble, and the length of the day, including the effects of the solid-earth tides and the earth's atmosphere. Part of this is summarized in the sections of the SAO Summer Seminar by Dr. G. Veis and Mr. Gaposchkin.

The structure and variation of the gravitational field in the neighborhood of the earth caused by the solar system are being investigated by Dr. W. Kohnlein. He is also directing the computer programming for an extended combination method (nonzonal harmonics and station coordinates) that will include laser distance measurements and gravity anomalies.

As part of his study of the proper interpretation of the satellite-derived geopotential, Dr. C.-Y. Wang examined how these data fitted with other information. He measured the pressure derivatives of sound velocity in some rocks and compared them with their densities. Using these data and others obtained by other authors, he found that a monotonic relation exists between the pressure derivatives of sound velocity and the density of rocks. The rocks with high density have lower values of the pressure derivatives, and vice versa. He speculates that velocity in oxides and silicates is determined by the mean atomic weight, or the mean volume per atom, of the crystals, but is independent of the chemical compositions. If granite is compressed to the density of corundum, its pressure derivative at that pressure should be equal to that of corundum at room pressure. In this way it may be possible to find, by numerical integration, the velocity of rocks at very high pressure, using only results obtained at low pressure.

Mr. A. Girnius continued an analysis of simultaneous satellite observations by Baker-Nunn cameras. The observational material increased by 60% since April 1966. The program yielding synthetic simultaneous observations requires considerable time and manual work for the preparation of input data. A more complete automation of this program is not foreseen in the near future since programmers are tied to the conversion of high-priority programs to the CDC 640, and more time is needed for the selection of preferable observations and the investigation of problematic cases (e.g., correlated synthetic simultaneous observations due to multiple overlapping). Therefore, as aids to analyzing simultaneous observations, two computer programs were made, one for drawing standard ellipses, and the other for computing longitudes and latitudes.

Mr. Girnius assisted Dr. Veis in the computations for a comparison of station positions obtained from photographic (SAO Baker-Nunn station) observations, which provide direction and orientation, and from radio-tracking (JPL, Deep Space Instrumentation Facility Station) observations, which provide scale. The agreement between both techniques was very encouraging. He also gave assistance to Mr. K. Lambeck on his continuing investigation of simultaneous observations by grouping them according to different criteria, and connected the Agassiz geodetic camera station to the U. S. Coast and Geodetic Survey control network.

Mr. J. Rolff visited six GEOS stations in Western Europe to discuss operational and scientific matters. As a result, all these stations have implemented better procedures.

Concerning the East European GEOS stations, Riga has reported many successful observations. Mr. Rolff also attended a symposium on "Scientific Problems Related to the Observation of Artificial Satellites" in Potsdam; most participants were from Eastern European countries. The discussions opened the way for a significant expansion of Russian-American cooperation.

Cooperation between SAO and the Western European countries on the passive satellites Echo and PAGEOS has also been expanded and is now functioning very smoothly. Another visit by Mr. Rolff to the Secretary of the West European Sub-Commission for Satellite Geodesy contributed significantly to securing this cooperation.

The Central Bureau for Satellite Geodesy distributed its second Bulletin (dealing with the PAGEOS satellite), as well as its second Bibliography on Satellite Geodesy.

Atmospheric Studies

Dr. L. G. Jacchia and Mr. J. Slowey have derived atmospheric densities from the orbital drag of satellites 1958 Alpha, 1959 Alpha 1, 1960 Xi 1, 1962 Beta Tau 2, 1963 53A, and 1964 76A, and used them to investigate the structure and variations of the upper atmosphere. Their aim is to have a continuous record of the detailed atmospheric variations over a large range in height and latitude. At the Inter-Union Symposium on Solar and Terrestrial Physics in Belgrade, August 1966, Dr. Jacchia presented results frorn a study of atmospheric perturbations connected with geomagnetic activity. He also reviewed upper atmosphere properties derived from satellite drag at the Discussion Meeting on Orbital Analysis held in London in October, under the auspices of the Royal Society.

Particular attention is being given to the diurnal variation in the upper atmosphere and its changes with latitude and seasons, in order to interpret the unexpected results obtained from the drag analysis of high-inclination satellites. With the help of Dr. M. P. Friedman, Dr. Jacchia is developing a theoretical model of the diurnal variation over the globe. They hope that a comparison of this model with the observed data will provide greater insight into the problem.

In addition to the satellites that are regularly used for monitoring atmospheric densities, Dr. Jacchia and his associates also analyze the drag of a few objects at great perigee heights, such as Echo 2 and 1963 30D. Although the effect of solar-radiation pressure makes the densities obtained from these satellites much less reliable, they can still be used to derive the magnitude of the atmospheric variations of known type at those heights, and thus provide a check on theory.

Dr. M. P. Friedman is now extending a set of equations to determine the structure of the upper atmosphere between approximately 120 and 1000 km in order to investigate the possibility of winds in the upper atmosphere.

Dr. N. Carleton and his associates pursued their laboratory experiments pertinent to the atomic and molecular processes by which the atmosphere is heated.

Dr. C. Papaliolios continued to try to determine accurately by absorption spectroscopy the lifetime of the $a^3\pi$ state of CO. This determination will allow absolute calibration of auger detectors used to measure fluxes of metastable molecules.

In the study of electron-impact excitation of atmospheric gases to metastable states, the need has come up for a large-aperture UV spectrometer.

The experiments of Dr. **A.** Lee are concerned with the excitation of ions by electrons at near-threshold energies, with special emphasis on cases of astrophysical interest. In order to measure the cross sections under single-collision conditions, he has adopted the crossed-beam technique.

In a recent paper, Bohm and Bub suggested an experiment to test their hidden variable quantum theory. **As** a by-product of SAO laboratory work, the experiment was quite easy to do and was performed. The conclusion is that if hidden variables exist, they have a lifetime $\tau < 2 \times 10^{-14}$ sec. This experiment is being written up for publication.

Laser Investigations

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Liaison was maintained as required with other organizations operating laser, UHF, and microwave tracking systems.

Consideration was given to the implementation of Dr. Kolaczek's proposed experiment involving satellite-star occultations.

Celestial Mechanics

Using the potential of the computer, Dr. S. E. Hamid initiated an attempt to systematize the derivation of the force function acting on artifical satellites. The analysis so far has been restricted to the part due to the oblateness of the disturbing function and to the case of lunar satellites. He has also studied the possibility of deriving on the computer Von Zeipel's method of general perturbations in order to obtain analytical solutions to the problem and has obtained encouraging results. **A** report on this work was given at the SAO Summer Seminar.

Drs. B. Marsden and J. Wright investigated the use of the relativistic equations instead of the Newtonian equations of motion for an artificial satellite. The relativistic effects on the predicted value of the radius vector, true longitude and perihelion were calculated and compared with the estimated errors of reducing the observations. The magnitudes of the differences are almost within experimental accuracy, but one must also know the other effects (oblateness, drag, etc.) accurately to separate out the relativistic effects. The relativistic construction due to the Sun was also studied.

Dr. Hamid also completed a program for deriving by the Gauss-Hill method secular perturbations due to the action of the different planets. In collaboration with Dr. Whipple, he applied this program to detect the effect of Whipple's cometary belt on the orbits of long-periodic comets. The effect has been found to be appreciable and within the reach of observation.

Another application of the program was to compute the secular perturbations of each planet due to the attraction of the other eight planets. The problem involved the solution of 48 simultaneous differential equations of the first order and degree. The values obtained for the secular perturbations of the four inner planets were found to agree very satisfactorily with those derived by Doolittle and Newcomb.

To study the effect of Jupiter on asteroidal evolution, Dr. Hamid developed for the computer a first-order theory of general perturbation of one disturbing planet on circular coplanar orbits. The disturbing body and its various derivatives have been expanded up to the second power of eccentricity of the disturbing planet and up to any given number of terms. A numerical criterion for the number of terms necessary in the expansion for a given radius of the orbit of the disturbed body was developed. Extending that work to include noncoplanar, noncircular disturbed orbits, he is now considering more powers of eccentricities, and higher order of masses.

Dr. J. Meffroy continued to investigate the elimination of the long-period terms as the second step in the building of a first-order general planetary theory through Von Zeipel's method.

Under the direction of Dr. Marsden, programs have been written by Mr. B. Benima to add, multiply, and differentiate trigonometric series analytically, and the disturbing function in planetary theory is being checked by means of them. Extensive tests on the orbit-computation programs by Mr. K. Aksnes and the n-body integration program by Mr. J. Schubart have been made, and further programs are now being written to link the two. Orbits and ephemerides have been prepared for the four comets discovered during the period under consideration. Dr. Marsden has also been working on the evolution of the sun-grazing comet group, and on an investigation of possible past observations of periodic Comet Swift-Tuttle, parent of the Perseid meteor stream, in the hope that it will be possible to predict its next return.

During the second half of 1966, Miss C. Munford, continuing with the research of Dr. Colombo on the gaps in the distribution of the mean motion of the asteroids, found several sets of periodic solutions.

After a slight modification in the computer program, she obtained more accurate values for the starting solutions of a few orbits, and can now proceed with an investigation into their stability.

Flare-Star Investigations

The flare-star program has continued in conjunction with Jodrell Bank, CSIRO, and various optical observatories using photoelectric means. In addition to obtaining Baker-Nunn films of prior observing periods and preparing a bibliography of all reported activity of the dMe flare stars, Mr. Solomon has commenced photoelectric observations, including monitoring of one suspected flare star (BD t 31° 1048) and determination of comparison-star magnitudes for the Baker-Nunn monitoring program, A search of Harvard plates for activity of the star BD t 31" 1048 proved negative, as did one of good Baker-Nunn observations, for a period reported to contain much activity of the star. It appears possible that the observations of activity were erroneous.

Mr. Solomon has also completed preliminary studies of optimum exposure and limiting magnitude of the Baker-Nunn camera and is working on the camera's photometric system. He prepared the results of Nova Hercules 1963 measurements for publication, and obtained for measurement films of a suspected new outburst of T Pyxidis.

EDITORJAL AND PUBLICATIONS

The Satellite-Tracking Program issued the following Special Reports during this 6-month period:

No. 216 -- On the gradient line of the earth's zonal gravitational potential by W. Köhnlein

No. 217 -- A critical survey of upper-atmosphere density measurements by means of ionization changes by M. P. Friedman

No. 218 -- Geomagnetic perturbations and upper-atmosphere heating by L. G. Jacchia, J. Slowey, and F. Verniani

No. 222 -- Satellite orbital data no. E-5 by B. Miller

No. 223 -- The short-period drag perturbations of the orbits of artificial satellites by L. Sehnal and S. B. Mills

No. 225 -- Satellite orbital data by B. Miller

No. 227 -- Catalog of precisely reduced observations no. P-15 by B. Miller

No. 230 -- Optimum stations-satellites configurations for simultaneous observations to satellites by K. Lambeck

'No. 231 -- Probability of recording satellite images optically by K. Lambeck

No. 232 -- Publication of orbits derived from photoreduced Baker-Nunn observations by E. M. Gaposchkin

No. 233 -- Systematic corrections to reduce certain early satellite positions to the FK-Y system by K. Haramundanis

No. 234 -- Note of expressions for second-order short-periodic perturbations by Y. Kozai

No. 235 -- Lunisolar perturbations with short periods by Y. Kozai